

Test Hardware Design for Flight-Like Operation of Advanced Stirling Convertors

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NASA Glenn Research Center (GRC) has been supporting development of the Advanced Stirling Radioisotope Generator (ASRG) since 2006. A key element of the ASRG project is providing life, reliability, and performance testing of the Advanced Stirling Convertor (ASC). For this purpose, the Thermal Energy Conversion branch at GRC has been conducting extended operation of a multitude of free-piston Stirling convertors. The goal of this effort is to generate long-term performance data (tens of thousands of hours) simultaneously on multiple units to build a life and reliability database. The test hardware for operation of these convertors was designed to permit in-air investigative testing, such as performance mapping over a range of environmental conditions. With this, there was no requirement to accurately emulate the flight hardware. For the upcoming ASC-E3 units, the decision has been made to assemble the convertors into a flight-like configuration. This means the convertors will be arranged in the dual-opposed configuration in a housing that represents the fit, form, and thermal function of the ASRG. The goal of this effort is to enable system level tests that could not be performed with the traditional test hardware at GRC. This offers the opportunity to perform these system-level tests much earlier in the ASRG flight development, as they would normally not be performed until fabrication of the qualification unit. This paper discusses the requirements, process, and results of this flight-like hardware design activity.



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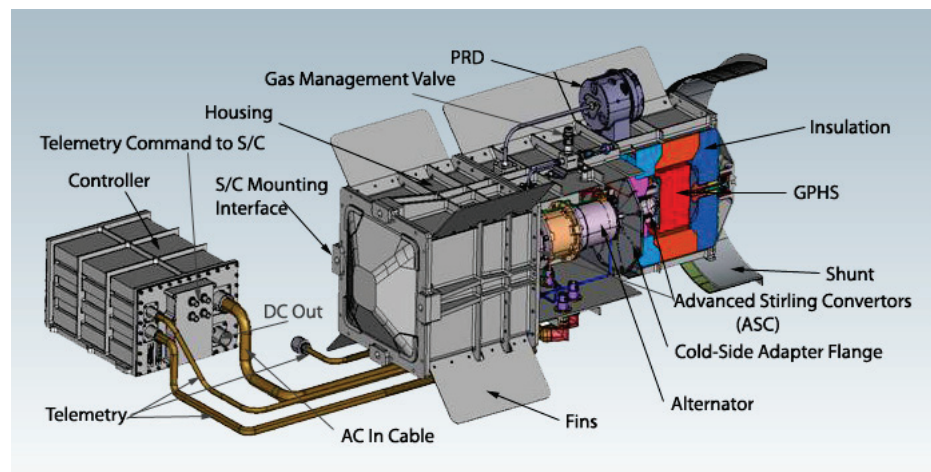
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Outline

- Advanced Stirling Radioisotope Generator (ASRG) and Advanced Stirling Convertor (ASC) Background
- Design Guidelines
- Design Concept
- Housing Material Substitution (Be vs. Al)
- Electric Heat Source
- Future Plans and Current Status
- Conclusion

ASRG and ASC Background

- ASRG being developed by Lockheed Martin for spacecraft power
- NASA GRC conducts ASC extended operation
- Provides performance data for life and reliability analyses
- To date : 220,000 hours on 20 ASCs
- Only two convertors in system-like config : ASRG-EU
- Upcoming ASC-E3s
 - Latest ASC design, up to 850 deg. C operation
 - Being built to flight drawings and quality procedures
 - Will be assembled in generator-like hardware to enable system-level testing



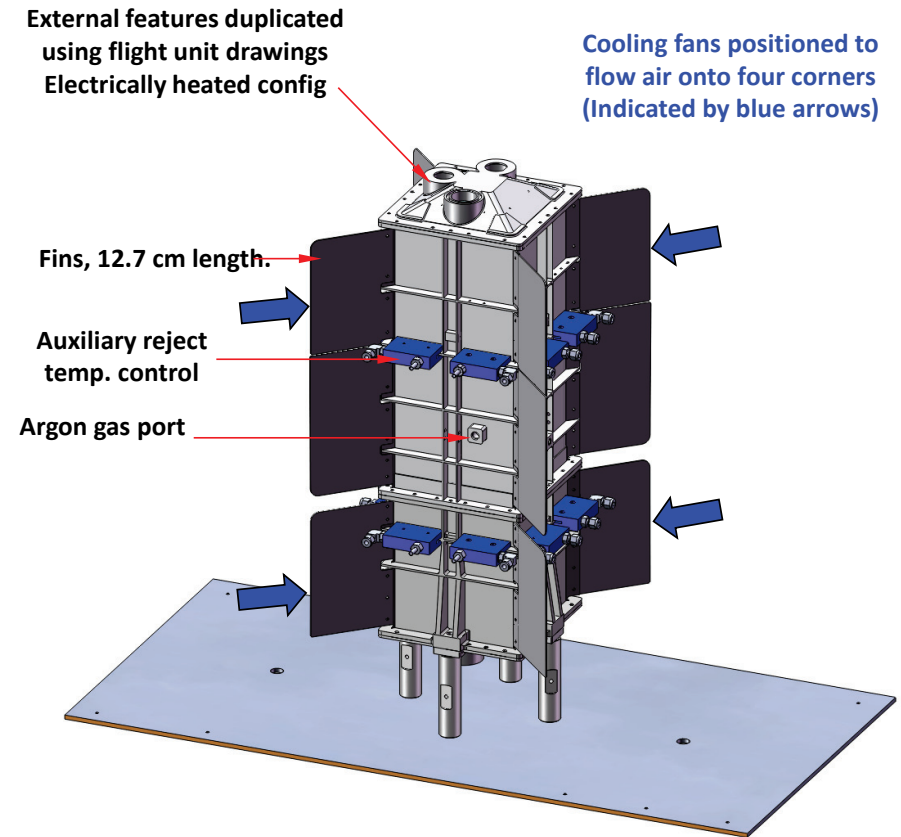
ASRG Flight Unit, courtesy of Lockheed Martin

Design Guidelines

- Emulates flight unit where possible
- Housing is heat rejection device
- Sealed, argon-filled internal environment
- Dual-opposed, vertical or horizontal
- Forced convection cooling for in-air operation
- Thermal vacuum-capable
- Emulates ASRG transient thermal response
- No requirement for vibe testing or structural dynamics
- Less expensive or simplified in these areas:
 - Aluminum instead of Beryllium
 - GRC-designed long life heat source

Design Concept

- **External flight features duplicated except:**
 - Aluminum 6061 T6 instead of Beryllium (only 12% less thermal conductivity)
 - No pressure relief device
 - Thermally-equivalent white paint
 - Auxiliary temp control cooling blocks
- **Variable-speed fans positioned to flow air onto fins**
- **Internal features duplicated except:**
 - Electric heat source
 - Heat source preload stud



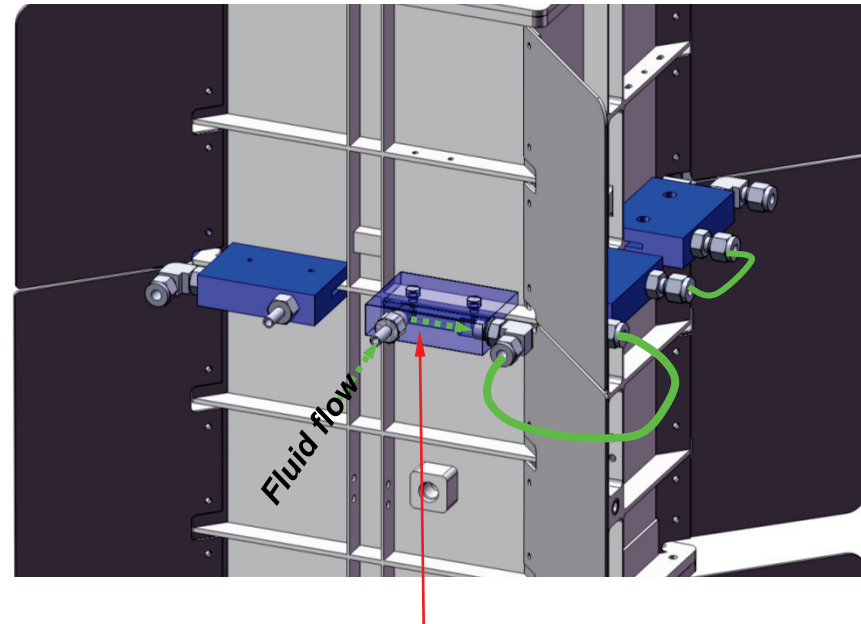
ASC-E3 Flight-Like Operation Concept

Effect of Aluminum Housing

- Aluminum is less expensive than beryllium and readily available
- Aluminum has lower thermal conductivity and lower heat capacity per volume

	Aluminum 6061 T6	Beryllium (ASRG)
Thermal Conductivity, W/mK	167	187
Heat capacity density, kJ/K/m³	2420	3470
Coefficient Thermal Expansion, ppm/K	23	12

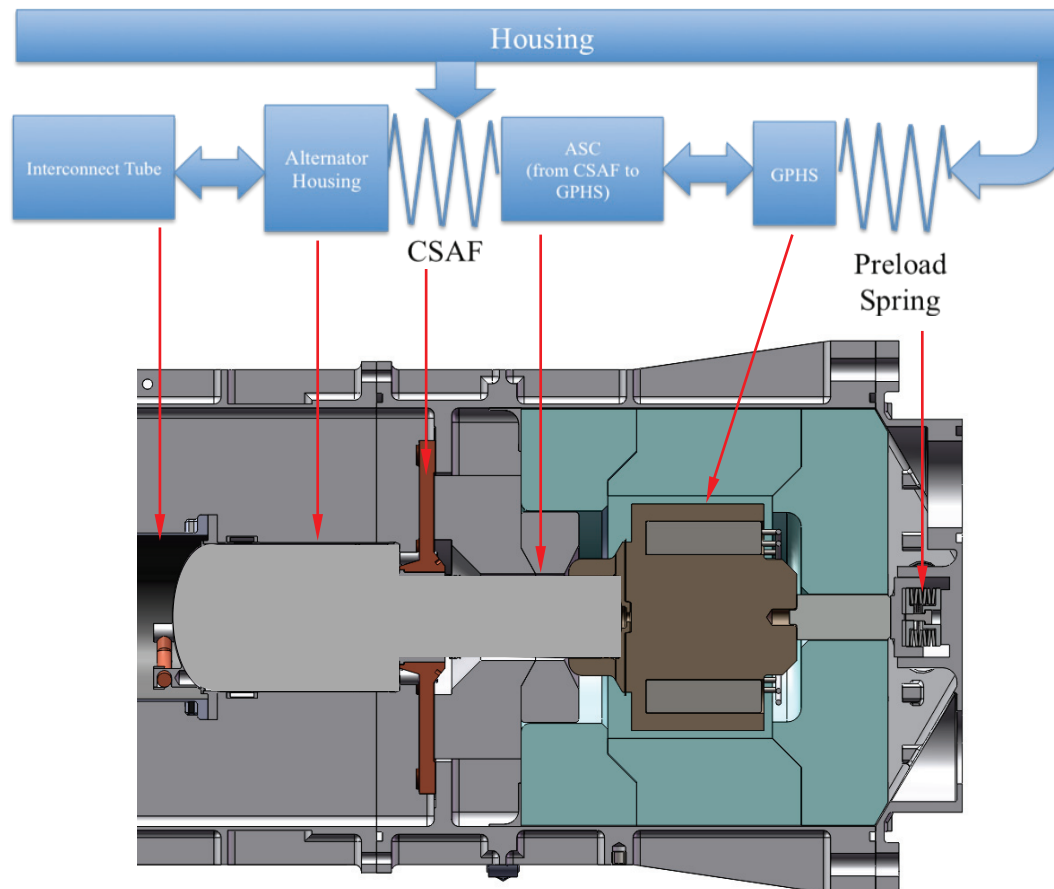
- Conduction path thickness increased by 12%
- Additional Al mass necessary to raise heat capacity
 - Needed for transient response
 - Will be used for auxiliary temperature control



*Aluminum blocks clamped to housing rib
around perimeter near each bulkhead
Also provide option for coolant flow*

Effect of Aluminum Housing

- Aluminum thermal expansion is twice that of beryllium
- Analyzed thermally-induced forces for various operating conditions
- Constructed linear thermal expansion model with stiffness for cold-side adapter flange (CSAF) and heat source preload



Effect of Aluminum Housing

- If interconnect tube is same length as flight design:
 - The forces are higher due to greater expansion of aluminum
 - Forces still within safe limits for convertor

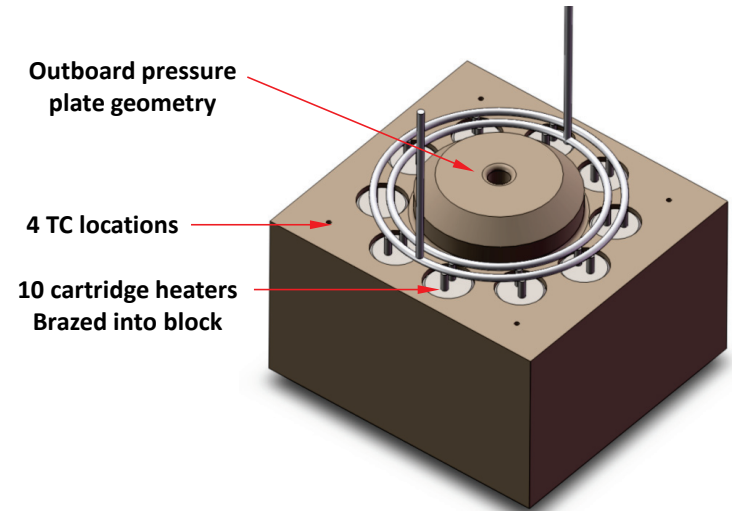
	@ Deep Space Sink Temp		@ Near Earth Sink Temp	
	Be	Al	Be	Al
Force exerted on convertor, N	-80	+173	-769	-992

Comparison of thermally-induced forces for beryllium and aluminum flight-like housings

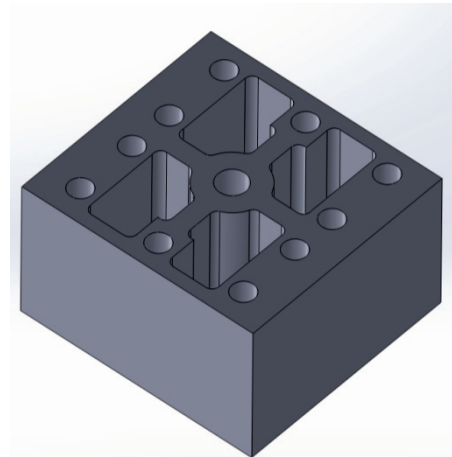
- Forces can be altered by adjusting convertor interconnect tube
- Only one environmental condition can be matched
- An extra 0.5 mm will match Beginning-of-Mission (BOM) Deep Space Sink Temp condition

GRC-designed Electric Heat Source

- **Decided to simplify electric heat source to reduce cost and extend life**
- **Design Requirements and Guidelines:**
 - Same geometry as GPHS + pressure plates
 - Long life (~20,000 hours)
 - Similar thermal properties to EHS and GPHS
- **Design Features:**
 - Solid nickel 201 block, integral pressure plate geometries
 - Brazed-in cartridge heaters, minimized heat flux
 - Spot-welded bus wire
 - Molybdenum can be used for lower thermal mass closer to GPHS module



Ni201 electric heat source



***Alternative molybdenum heat source
option for lower thermal mass***

Future Plans

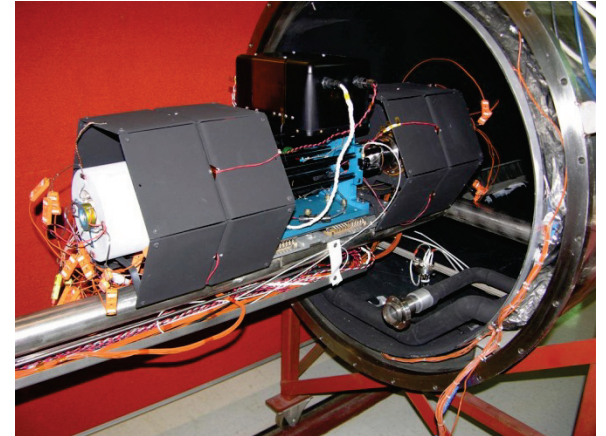
- The flight-like ASC-E3 configuration is planned for a series of system-level tests, for example:

- Mock fueling
- Argon vent simulation
- Thermal-vacuum operation
- Flight prototype controller performance
- Simulating various mission environments

- **Availability : Q1 FY13**

- **Status**

- Initiated fabrication of long-lead housing components
- Using in-house rapid prototyping (FDM) for part mockups



Example ASC-0 thermal vacuum test article



Example 3D-printed housing piece for solid model and assembly fit checks

Conclusion

- **NASA GRC is designing test hardware that will emulate the ASRG flight-unit**
- **Aluminum will take place of beryllium**
- **The effect of aluminum has been analyzed and corrected**
- **A long-life electric heat source has been designed**
- **Hardware will be used for system-level tests as well as extended operation**